Minutes & Notes from Proton Driver RF Meeting March 02 2004

The subject of the meeting was the coaxial shorted-stub option for the ferrite tuner.

Attendees: Ding Sun, Vladimir Kashikhin, Dave Wildman, Jim Strait, Nickolay Solyak, Pierre Bauer, Marcus Huening, Iouri Terechkine, Gennady Romanov,, Bill Foster

GENERAL NOTES:

The coaxial stub tuner is an alternative to the ferrite-loaded waveguide stub investigated for use in the SNS and (apparently, judging from the dimensions) for the AFT quote for the I-Q modulator. Advantages include a potentially a simpler solenoidal geometry for the biasing magnets, possibly more efficient use of ferrite material, an easier geometry for cooling, and an EM field geometry that even the boss can understand. Disadvantages are the necessity of a waveguide-to-coax transition, a more complicated ferrite geometry (ferrite rings vs. ferrite slabs), and higher RF surface current losses.

The present R&D plan is to:

1) Have one or more commercial 805 MHz IQ modulator prototypes built along the lines of the quote that Al Moretti obtained from AFT (Advanced Ferrite Technology). Changes in the specification include a reduced tuning range range of +/-45 degrees in each stub, and a response time of 100 microseconds for a 45-degree phase jump. Fermilab will take responsibility for the bias power supply design, which will hopefully save money. These specifications imply a maximum voltage attenuation factor of sin(45 degrees) = 0.707 at zero phase shift, and a maximum phase shift of 45 degrees at zero attenuation. The spec will be prepared by Al Moretti (AD) and N. Solyak and Iouri Terechkine (TD) and the order (to one, or perhaps two companies) will be placed using existing TD funds as soon as possible.

2) Pursue an in-house protoype program for the coaxial shorted-stub tuner option for the E-H tuner. More on this below.

3) Try to invent simpler geometries than the two-stub E-H Hybrid tuner for obtaining the limited range of phase and amplitude adjustment required. One option that received some interest is a “three stub” tuner where two or three of the “stubs” were coax tuners with their center conductors extending into the waveguide. Other options involve in-line coaxial phase shifters in combination with quarter-wave resonators to provide an “adjustable cavity coupler” with the side benefit of reducing the cavity fill time.

MINUTES

Dave Wildman described the results he and Al Moretti obtained with the coaxial phase shifter in the 805 MHz test stand. The pre-existing YIG tuner (not fair to even call it a prototype since it was designed for a different frequency) was used successfully to tune a 159 MHz cavity in the main ring. When operated at 805 MHz at power levels up to ~0.5 MW, and biased above resonance, it exhibited a reflective phase shift of ~50 degrees and with an attenuation that was not well calibrated but was in the range of the ~0.2 dB target. It exhibited a number of spurious resonances that Dave believed were radial "pillbox" modes due to the copper cooling washers between the ferrite rings.

Dave identified a couple of papers which he found useful for describing coax tuners. Marcus Huening absconded with one copy, scanned it in, and it has been added to the trove of useful papers:
http://tdserver1.fnal.gov/8gevlinacPapers/Ferrite_Tuners/TRIUMF_FerriteGarnet_Tuners.pdf

Some discussion of the field penetration time of the prototype. In it's previous use, it had successfully tracked the Main Ring RF for 10 msec, indicating to Dave a likely response time of order 1 msec. Iouri Terechkine was questioning whether the device as built would fully respond in a millisecond, since the coax was surrounded by a solid copper ring which would generate an eddy current tending to buck out any rapid change in the B-field from the bias solenoid.

Vladimir Kahikhin will perform time dependent 2-D eddy current calculations for a representative solenoid geometry: Ferrite rings 3" OD, 0.5" ID, five rings 0.5 thick=2.5" total length. The goal is to estimate the field penetration time in various coil and coax shield geometries. First candidates for the coax shell will be a stainless (or Inconel?) tube with copper plating on the ID. First guess at the waveform will be a magnetic field ramp (voltage pulse) to bias the ferrite above resonance (~1 kGauss) before the RF pulse starts, then the feedback loop will slew the bias field arbitrarily between 1-1.5 kG to control the phase shift. The response time target is 100usec for a magetic field step of +/-0.25kG starting at 1.25kG. The ferrite will saturate as the bias is applied but remain fully saturated during the RF Pulse (phase feedback) time, so the response will be limited by the coax metal shell and coil (inductance) properties.

Discussion of the response time spec for the tuner: Marcus Huening's simulation indicates that the major speed requirement is on the phase response of the tuner, since this is used to track the microphonics and residual Lorentz detuning of the cavities. The amplitude response is used only to provide the individual filling amplitudes during the cavity filling times, which can be a relatively slow (pre-programmed) curve for each cavity. These requirements are very good news for the IQ modulator design based on the E-H tuner principle. When the E-H tuner is at maximum amplitude (phasors from both stubs parallel) there is no amplitude response (to first order) from a differential phase shift of both stubs. In contrast the phase response at the output to a common-mode phase shift of both stubs is immediate.

Some discussion of bias above/below resonance: There appears to be a consensus that operating above resonance will be necessary, even though it costs extra for the bias power supply. If the bias supply looks painful, we can consider using permanent magnets as the AFT 353 MHz tuners do. However the AFT tuners operate CW and we are pulsed with a 1.5% duty factor, so we may be OK without permanent magnets. The permanent magnets may provide some safety factor since a failure of the control system is less likely to put the ferrite on resonance when the RF is on. Vladimir K. indicated that there were solenoidal permanent magnet geometries which might provide the bias field. However the stray fields would have to be very carefully controlled, since magnetic fields at the (tens of microgauss level?) are sufficient to kill the cavity Q if they are present during cavity cool-down.

Discussion of the uniformity of the bias field: Dave Wildman felt that as long as the entire volume of the ferrite was above resonance, the exact distribution of the field strength did not matter much.

Discussion of higher order modes in coax tuner: Trapped HOM's may be generated in the coax stub due to geometrical imperfections, inhomogeneities in the magnetic bias field, radial modes from cooling washers, or penetration of evanescent HOMs from the doorknob transition. A smaller radius coax will push these modes up in frequency, at the cost of power handling capability and ease of cooling. The Bell Labs coax tuner used a very small coax (7/8"?) and the paper mentioned a "rule of thumb" for avoiding HOM trouble in tuners. Some of this might be studied with simulation codes.

Dave W. obtained a quote and prepared a purchase req. for YIG rings suitable for constructing a 50-Ohm line (3"OD x 0.5"ID x 0.5"thick). Very cheap ($3k for 20 pcs?), 12 week delivery. Pierre Bauer is getting the req through TD ASAP. Expediting the delivery time would be considered by the company once the order has been placed. GWF allowed for the possibility of expediting the delivery time by spending $1K extra per month of expedited delivery.

N. Solyak found similar materials from Ferrite Domen (St. Petersburg), which GWF indicated we should also buy prototype quantities from if the price is similar. Ding indicated that the 510 material is a semi-standard product which appears to be available from multiple vendors.

Dave indicated the material should work well at 1.3 GHz as well as 805MHz. Question arose whether the we should look at smaller coax geometries in case we get in trouble with HOMs. Iouri felt the cooling would get much harder. So we go with same dimensions from all vendors so we can do interchangable tests.

[editor's note: after the meeting, Pierre Bauer indicated that he is nearly up to speed on running Marcus' simulation code. This is very good news, since sharpening our pencils on the tuner spec is a high-payoff activity].

[Ding Sun also indicated that he had successfully replicated in simulation the experimental results for the "waveguide style" SNS R&D by Kang et. al. The major uncertainty is the field in the biasing magnet.]

AGENDA ITEMS FOR NEXT MEETING

(I won't be there next week, so you can interpret these things as items to be accomplished before, during, or after next Tuesday's meeting. I'm asking Pierre Bauer to take minutes.)

- Bauer/Wildman: progress report on getting the Ferrite ordered (& expedited?)

- Vladimir/Steve Hays first cut at the bias coil & power supply requirements for a pulsing the coax tuner at 10 Hz with a 1.5 msec (programmable) flat top.

- Moretti/Solyak/Terechkine: next iteration of bid spec for 805 MHZ IQ modulator

- All RF Simulation wonks: how are we set for RF simulation tools:

  A) for simulating the circularly polarized waved in the biased ferrite in the "waveguide" designs, and
  B) if we restrict ourselves to (metal waveguide structures plus coaxial ferrite tuners)

- All: any bright ideas for simplifying the E-H tuner topology given our limited requirement for range of phase and attentuation?